

## Phytoplankton composition and biomass of the northern Adriatic lagoon of Stella Maris, Croatia

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This study provides information on the seasonality of phytoplankton abundance, biomass expressed as cell volume and cell carbon, as well as species composition, in the small, shallow, brackish northern-Adriatic lagoon of Stella Maris near Umag (Croatia). The lagoon is permanently connected with the adjacent sea. Wide seasonal temperature and salinity excursions regulate phytoplankton assemblages. Unlike other Adriatic lagoons, the lagoon of Stella Maris showed moderate phytoplankton abundance, cell volume and carbon content and a high number of species. The specific diatom volumes from the Stella Maris lagoon were higher than those found in other Adriatic lagoons, whereas the specific volumes of dinoflagellates were in the same range. Diatoms represented 55% of all the species found, but there was a considerable contribution of nanoplankton and dinoflagellates in the annual outbursts.

**Keywords:** phytoplankton, taxonomy, cell volume, cell carbon, coastal lagoon, Adriatic Sea

### Introduction

The lagoons of the northern Adriatic Sea are characterized by shallowness, strong influence from the adjacent land and considerable fluctuations in hydrographic conditions. The lagoons of the northwest Adriatic coast have been studied with much attention for over two centuries (NARDO 1847, NINNI 1906, BABIĆ 1911, KIESSELBACH, 1936, BRUNETTI et al. 1983, OREL et al. 2001, COVELLI et al. 2005), particularly with respect to lagoon phytoplankton (VATOVA 1940, 1961; MARCHESONI 1954; TOLOMIO 1982; TOLOMIO and BULLO 2001; FACCA et al. 2002, 2003; SOCAL et al. 2006). However, on the eastern coast the few lagoons have been investigated only sporadically (ZANON 1941; MALEJ et al. 1979; FANUKO 1979, 1984; DE MENECH 2005; FANUKO et al. 2008).

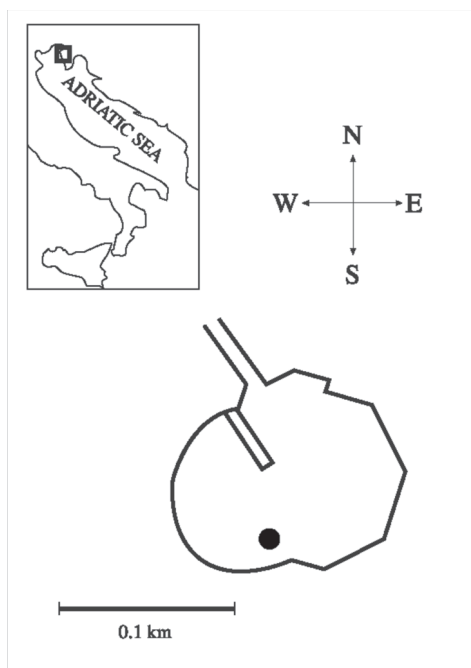
This paper provides information on phytoplankton assemblages, their species composition, abundance, cell volume and carbon in the small, shallow brackish lagoon of Stella Maris near Umag (Croatia).

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## Materials and methods

### Study area

The study area is a small, natural macro-tidal northern Adriatic lagoon ( $45^{\circ}27'06.35''\text{N}$ ,  $13^{\circ}30'59.80''\text{E}$ ), only 15,000 square meters large and 2 m deep in most parts, permanently connected with the adjacent sea by a narrow channel, 6 m wide and 40 m long (Fig. 1). The climate of the region is sub-Mediterranean with an average annual air temperature of  $16.4^{\circ}\text{C}$  and a rainfall up to 1,000 mm per year, distributed mostly over autumn and winter. In the lagoon there are several submarine springs, active mostly during late autumn and winter. The level and water exchange inside the lagoon is influenced generally by the tidal range of up to 2.04 m, while the prevailing weak winds from west and southwest probably represent an additional forcing factor. The euphotic zone comprises the whole water column. The water temperature varies in a wide range, from  $4.2^{\circ}\text{C}$  in January to  $30.2^{\circ}\text{C}$  in July and the salinity, ranging from 29 to 37, is directly influenced by daily events: rainfall and subsurface spring activities, with the highest values, above 33, observed in summer. The lagoon is located in the middle of a tourist resort, where bungalows are inhabited only during spring and summer. In 1979 the lagoon and the channel were deepened, a pier and lateral quays were erected, transforming the lagoon into a small marina, equipped with water and electricity supply, accessible to vehicles, with one hundred moorings for smaller boats anchoring between April and October, reaching the maximum number in August. During the cold part of the year the lagoon is entirely abandoned and the only human activity inside is sporadic fishing.



**Fig. 1.** Location of Stella Maris lagoon with sampling site

The sandy to muddy sediments are populated by eelgrass *Cymodocea nodosa* which dominates the macroalgae *Chaetomorpha* sp. and *Cystoseira* sp. in winter and spring and *Padina pavonica* in summer. In autumn and winter, when anthropogenic influence is sparse, the lagoon becomes a habitat for 3 species of water birds: *Tachybaptus ruficollis*, *Aythya fuligula* and *Larus genei*. Occasionally from May to September a mucilage phenomenon extending from surface to bottom is observed, in the same days but to a greater extent than in the outside sea.

### Phytoplankton

From September 2004 to September 2005, with the exception of October, January and February, the sampling was carried out once or twice a month at the 1 m deep station. The phytoplankton samples for microscopic analysis were preserved with buffered formaldehyde (1.5% final concentration) and the subsamples (50 mL) were settled overnight in sedimentation chambers. The entire bottom chamber plate area was counted at 250 $\times$  magnification for cells larger than 10  $\mu$ m, whereas for smaller cells (< 10  $\mu$ m) one transect of the chamber bottom was scanned at 500 $\times$  magnification. The species were identified and classified according to STREBLE and KRAUTER (1984) for cyanobacteria, THRONDSSEN (1997) for naked flagellates, HEIMDAL (1997) for coccolithophorids, PERAGALLO and PERAGALLO (1908), HUSTEDT (1930), HENDEY (1964) and HASLE and SYVERTSEN (1997) for diatoms, STEIDINGER and TANGEN (1997) for dinoflagellates. Cells of approximately 2  $\mu$ m in size that were hard to identify were reported as minute nanoplankton.

During each count, linear measurements of cell size, made by ocular micrometer, were made for 3 to 5 specimens of perennial species and every specimen of rare species. These values were converted to specific average biovolume using the geometric formula of either a sphere, a parallelepiped, a cylinder, a cone or truncated cone, an ellipsoid or two composite geometric bodies. The average cell volume was converted to cell carbon using the conversion factor of 0.13 pg C  $\mu$ m<sup>-3</sup> for armoured dinoflagellates and 0.11 pg C  $\mu$ m<sup>-3</sup> for other phytoplankton groups (ANDERSSON and RUDEHÅLL 1993).

## Results

### Species composition and phytoplankton successions

The phytoplankton assemblage of the Stella Maris lagoon was composed of 151 taxa (Tab. 1). Diatoms were the dominant group (55% of all the species found), followed by dinoflagellates (28%) and prymnesiophytes (7%). The shallow lagoon assemblage was characterized by 21 genera of pennate diatoms that appeared throughout the year in low but steady number and were obviously well adapted to the fluctuating abiotic variables. The microscopic observations revealed that the winter specimens of these pennate diatoms had larger chloroplasts, which were more abundant and more intense in colour than those observed in the cells of the same species that appeared in summer.

The outbursts of abundance, cell volume or phytoplankton carbon were caused by other groups. In March 2005, when the sea temperature was 12 °C and the salinity 34.4, the coccolithophorid *Acanthoica aculeata* reached its maximum of 1.52 $\times 10^5$  cells L<sup>-1</sup>, while in May, when water temperature and salinity rose over 20 °C and 33 respectively, dinofla-

**Tab. 1.** List of the phytoplankton species found in the Stella Maris lagoon, their average cell volume and carbon content

T a x o n	cell volume ( $\mu\text{m}^3$ )	cell carbon content (pgC)
<b>CYANOBACTERIA</b>		
<i>Aphanizomenon gracile</i> Lemmermann	25	3
<i>Dactylococcopsis acicularis</i> Lemmermann	157	17
<i>Oscillatoria</i> sp.	19	2
<i>Phormidium faveolarum</i> Montagne ex Gomont	6	1
<i>Synechococcus aeruginosus</i> Nägeli	462	51
<b>CRYPTOPHYCEAE</b>		
<i>Hillea fusiformis</i> Schiller	14	2
<b>CHRYSOPHYCEAE</b>		
<i>Dictyocha fibula</i> Ehrenberg	2094	230
<i>Meringosphaera tenerrima</i> Lohmann	268	29
<i>Mesocena polymorpha</i> Lemmermann	3534	389
<i>Uroglena volvox</i> Ehrenberg	28	3
<b>PRYMNESIOPHYCEAE</b>		
<i>Acanthoica aculeata</i> Kamptner	133	15
<i>Calyptosphaera oblonga</i> Lohmann	1047	115
<i>Calciosolenia murrayi</i> Gran	209	23
<i>Emiliania huxleyi</i> (Lohmann) Hay et Mohler	268	29
<i>Michaelsarsia adriatica</i> (Schiller) Manton, Bremer et Oates	335	37
<i>Ophiaster formosum</i> Gran	34	4
<i>Ophiaster hydroideus</i> (Lohmann) Lohmann	26	3
<i>Prymnesium parvum</i> Carter	56	6
<i>Rhabdosphaera stylifera</i> Lohmann	524	58
<i>Syracosphaera pulchra</i> Lohmann	717	79
<b>BACILLARIOPHYCEAE</b>		
<b>C e n t r a l e s</b>		
<i>Biddulphia biddulphiana</i> (Smith) Boyer	395640	43520
<i>Biddulphia titiana</i> Grunow	339120	37303
<i>Cerataulina pelagica</i> (Cleve) Hendey	44179	4860
<i>Chaetoceros affinis</i> Lauder	15708	1728
<i>Chaetoceros brevis</i> Schütt	3402	374
<i>Chaetoceros compressus</i> Lauder	2650	291
<i>Chaetoceros curvisetus</i> Cleve	2011	221
<i>Chaetoceros decipiens</i> Cleve	282743	31102
<i>Chaetoceros peruvianus</i> Brightwell	261979	28818
<i>Chaetoceros simplex</i> Ostensfeld	34	4
<i>Chaetoceros tetrastichon</i> Cleve	942	104
<i>Chaetoceros tortissimus</i> Gran	877	96
<i>Chaetoceros wighami</i> Brightwell	1356	149
<i>Coscinodiscus excentricus</i> Ehrenberg	9770	1075

Tab. 1. – continued

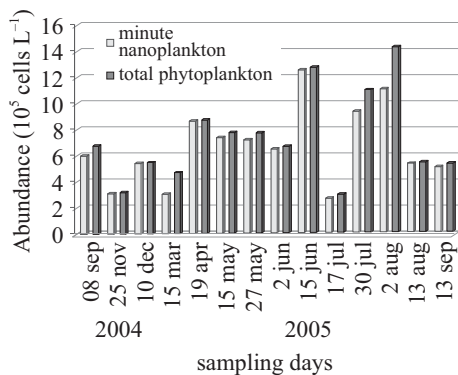
T a x o n	cell volume ( $\mu\text{m}^3$ )	cell carbon content (pgC)
<i>Coscinodiscus perforatus</i> Ehrenberg	1286	141
<i>Guinardia flaccida</i> Castracane (Peragallo)	1781283	195941
<i>Hemiaulus hauckii</i> Grunow	80592	8865
<i>Leptocylindrus danicus</i> Cleve	7853	864
<i>Leptocylindrus minimus</i> Gran	125	14
<i>Melosira nummuloides</i> Agardh	785	86
<i>Melosira sulcata</i> (Ehrenberg) Kützing	1155	127
<i>Odontella mobiliensis</i> (Bailey) Grunow	196250	21587
<i>Proboscia alata</i> (Brightwell) Sundström	6283	691
<i>Pseudosolenia calcar avis</i> (Schultze) Sundström	1178097	129591
<i>Rhizosolenia styliformis</i> Brightwell	105029	11553
<i>Skeletonema</i> sp.	2356	259
<i>Thalassiosira decipiens</i> (Grunow) Jørgensen	17671	1944
<b>P e n n a l e s</b>		
<i>Achnantes brevipes</i> Agardh	117810	12959
<i>Achnantes longipes</i> Agardh	376991	41469
<i>Amphiprora sulcata</i> O'Meara	4385	482
<i>Amphora crassa</i> Gregory	2880	317
<i>Amphora hyalina</i> Kützing	3240	356
<i>Amphora marina</i> (W Smith) Van Heurck	78540	8639
<i>Amphora ostrearia</i> Brébisson	165360	18190
<i>Amphora ovalis</i> Kützing	180	20
<i>Amphora sulcata</i> (Brébisson) Cleve	5000	550
<i>Amphora</i> sp.	2880	317
<i>Auricula adriatica</i> Peragallo	19250	2117
<i>Auricula insecta</i> (Grunow) Cleve	24000	2640
<i>Campylodiscus adriaticus</i> Grunow	28260	3109
<i>Cocconeis scutellum</i> Ehrenberg	943	104
<i>Cylindrotheca closterium</i> (Ehrenberg) Reimann et Lewin	524	58
<i>Diploneis bombus</i> Ehrenberg	6250	687
<i>Diploneis crabro</i> Ehrenberg	14400	1584
<i>Entomoneis paludosa</i> (W. Smith) Reimer	11025	1213
<i>Fragilaria crotonensis</i> Kitton	707	78
<i>Grammatophora marina</i> (Lyngbye) Kützing	8000	880
<i>Grammatophora oceanica</i> Ehrenberg	16000	1760
<i>Licmophora communis</i> (Heiberg) Grunow	1600	176
<i>Licmophora flabellata</i> (Carmichael) Agardh	12087	1330
<i>Licmophora lyngbyei</i> (Kützing) Grunow	27500	3025
<i>Licmophora paradoxa</i> (Lyngbye) Agardh	6480	713
<i>Licmophora quadriplacata</i> Mereschkowsky	126	14
<i>Licmophora remulus</i> Grunow	30000	3300
<i>Licmophora</i> sp.	6480	713

Tab. 1. – continued

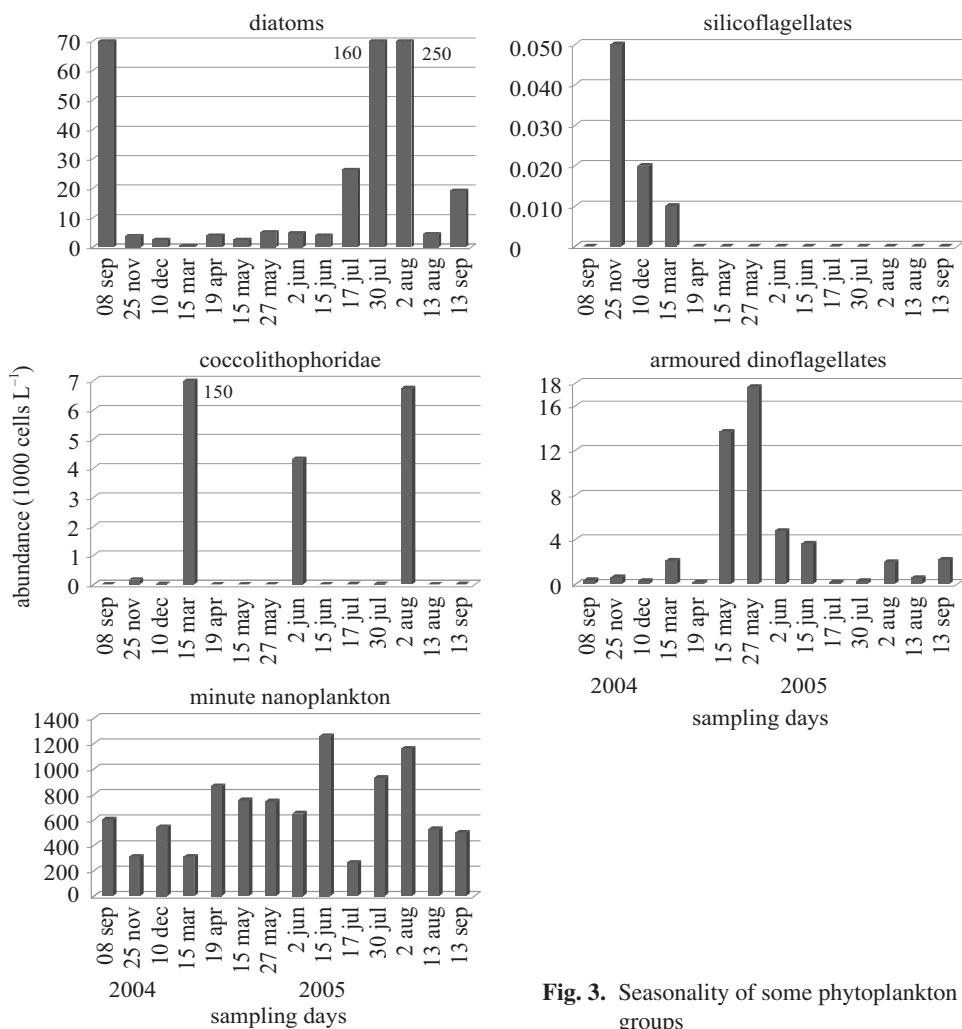
T a x o n	cell volume ( $\mu\text{m}^3$ )	cell carbon content (pgC)
<i>Lioloma pacificum</i> (Cupp) Hasle	5655	622
<i>Mastogloia asperula</i> Grunow	6000	660
<i>Mastogloia citrus</i> Cleve	2400	264
<i>Navicula cancellata</i> Donkin	3000	330
<i>Navicula lyra</i> Ehrenberg	3900	429
<i>Navicula</i> spp.	6000	660
<i>Nitzschia incerta</i> Grunow	6000	660
<i>Nitzschia longissima</i> (Brébisson) Ralfs	3351	369
<i>Pleurosigma angulatum</i> (Quekett) W. Smith	255563	28112
<i>Pleurosigma balticum</i> Smith	180000	19800
<i>Pleurosigma elongatum</i> W. Smith	144000	15840
<i>Pleurosigma formosum</i> W. Smith	194000	21340
<i>Podocystis adriatica</i> Kützing	73476	8082
<i>Pseudo-nitzschia</i> sp. 1	147	16
<i>Pseudo-nitzschia</i> sp. 2	1800	198
<i>Striatella unipunctata</i> (Lyngbye) Agardh	252500	27775
<i>Surirella fluminensis</i> Grunow	15000	1650
<i>Synedra crystallina</i> (Agardh) Kützing	19110	2102
<i>Synedra fasciculata</i> (Agardh) Kützing	4500	495
<i>Synedra hennedyana</i> Gregory	22973	2527
<i>Synedra tabulata</i> (Agardh) Kützing	5655	622
<i>Synedra toxoneides</i> Castracane	1050	115
<i>Synedra</i> sp.	5655	622
<i>Thalassionema nitzschioides</i> (Grunow) Mereschkowsky	120	13
<i>Thalassionema frauenfeldi</i> (Grunow) Hallegraeff	3750	412
<i>Toxarium undulatum</i> Bailey	22973	2527
<i>Tropidoneis lepidoptera</i> (Gregory) Cleve	60000	6600
EUGLENOPHYCEAE		
<i>Euglena viridis</i> (O.F. Müller) Ehrenberg	3142	346
<i>Eutreptia lanowii</i> Steuer	1571	173
DINOPHYCEAE		
<i>Alexandrium minutum</i> Halim	3462	450
<i>Ceratium furca</i> (Ehrenberg) Claparède et Lachmann	36559	4753
<i>Ceratium fusus</i> (Ehrenberg) Dujardin	9739	1266
<i>Ceratium macroceros</i> (Ehrenberg) Vanhöfen	39270	5105
<i>Ceratium massiliense</i> (Gourret) E.G. Jørgensen	188495	24504
<i>Ceratium tripos</i> (Müller) Nitzsche	150795	19603
<i>Dinophysis caudata</i> Seville-Kent	104720	13614
<i>Dinophysis fortii</i> Pavillard	111910	14548
<i>Dinophysis hastata</i> Stein	85910	11168
<i>Dinophysis schroederi</i> Pavillard	91630	11912
<i>Goniodoma polyedricum</i> (Pouchet) Jørgensen	38288	4977

Tab. 1. – continued

T a x o n	cell volume ( $\mu\text{m}^3$ )	cell carbon content (pgC)
<i>Goniaulax polygramma</i> Stein	22725	2954
<i>Gymnodinium simplex</i> (Lohmann) Kofoid et Swezy	589	65
<i>Gymnodinium sp.</i>	589	65
<i>Gyrodinium fusiforme</i> Kofoid et Swezy	21206	2333
<i>Gyrodinium sp.</i>	21206	2333
<i>Oxytoxum longiceps</i> Schiller	1571	204
<i>Oxytoxum tessellatum</i> (Stein) Schütt	1140	148
<i>Oxytoxum variabile</i> Schiller	697	91
<i>Phalacroma rotundatum</i> (Claparede et Lachmann) Kofoid et Michener	6936	902
<i>Prorocentrum arcuatum</i> Issel	29438	3827
<i>Prorocentrum balticum</i> (Lohmann) Loeblich	173	22
<i>Prorocentrum compressum</i> (Bailey) Abé ex Dodge	22808	2965
<i>Prorocentrum dactylus</i> (Stein) Dodge	18850	2450
<i>Prorocentrum gracile</i> Schütt	2566	334
<i>Prorocentrum lima</i> (Ehrenberg) Dodge	14158	1841
<i>Prorocentrum micans</i> Ehrenberg	13090	1702
<i>Prorocentrum minimum</i> (Pavillard) Schiller	2545	331
<i>Prorocentrum scutellum</i> Schröder	20944	2723
<i>Prorocentrum triestinum</i> Schiller	785	102
<i>Protoperidinium crassipes</i> (Kofoid) Balech	174411	22673
<i>Protoperidinium depressum</i> (Bailey) Balech	184103	23933
<i>Protoperidinium diabolus</i> (Cleve) Balech	150795	19603
<i>Protoperidinium divergens</i> (Ehrenberg) Balech	110733	14395
<i>Protoperidinium globulus</i> (Stein) Balech	2617	340
<i>Protoperidinium kofoidi</i> Fauré-Fremiet	233674	30378
<i>Protoperidinium leonis</i> (Pavillard) Balech	11641	1513
<i>Protoperidinium pallidum</i> (Ostenfeld) Balech	102108	13274
<i>Protoperidinium solidicorne</i> (Mangin) Diwald	43422	5645
<i>Protoperidinium steinii</i> (Jørgensen) Balech	63617	8270
<i>Protoperidinium tuba</i> (Schiller) Balech	3393	441
<i>Protoperidinium sp.</i>	63617	8270
<i>Scripsiella trochoidea</i> (Stein) Loeblich	6283	817
<i>dinoflagellate cyst 1</i>	8831	971
<i>dinoflagellate cyst 2</i>	14130	1554
CHLOROPHYCEAE		
<i>Carteria marina</i> Diesing	188	21
<i>Chlamydomonas sp.</i>	385	42
<i>Dunaliella sp.</i>	198	22
<i>Tetraselmis sp.</i>	385	42
<i>minute nanoplankton</i>	6	1
<i>incertae sedis</i>	785	86



**Fig. 2.** Annual variation of phytoplankton abundance



**Fig. 3.** Seasonality of some phytoplankton groups



gellates (*Goniaulax*, *Gymnodinium*, *Prorocentrum*, *Protoperidinium*, *Scropsiella*) became more abundant though their number never exceeded  $5 \times 10^4$  cells  $L^{-1}$ . In July and August the two centric diatoms were blooming: *Skeletonema* sp. and *Chaetoceros simplex* with  $1.57 \times 10^5$  cells  $L^{-1}$  and  $2.33 \times 10^5$  cells  $L^{-1}$  respectively. *Skeletonema* sp. appeared when the temperature and salinity conditions were among the highest registered (30.2 °C and 36.2). In terms of abundance the minute nanoplankton cells were the most conspicuous group throughout the year (Fig. 2), contributing up to 91% of the average annual phytoplankton abundance.

Seasonality in diatoms showed bimodal annual pattern and they were most abundant in summer and autumn; the silicoflagellates appeared in modest abundances in autumn, the coccolithophorids appeared from March to August, while the armoured dinoflagellates were most abundant in May (Fig. 3).

### Abundance, cell volume and carbon stock

Maximum abundances of the small nanoplankters ( $1.3 \times 10^6$  cells  $L^{-1}$  and  $1.1 \times 10^6$  cells  $L^{-1}$ ) were registered in June and August with a sharp decrease in July, which coincided with the increase of oligotrich ciliate density (results not shown) and could be explained as a

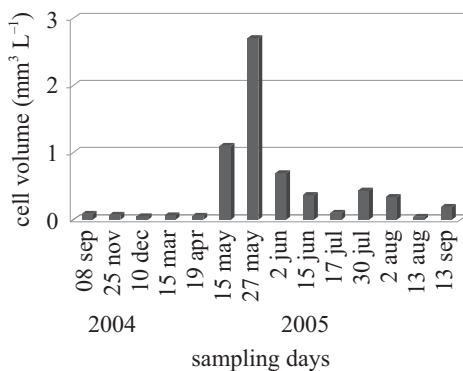


Fig. 4. Seasonal changes in phytoplankton cell volume

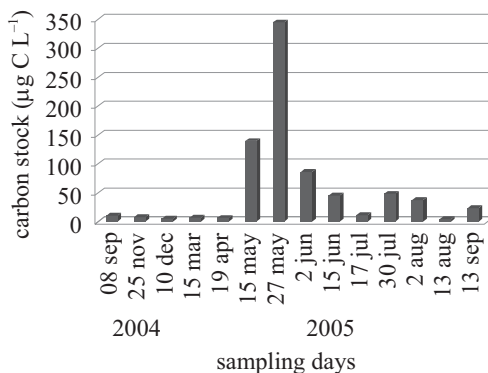
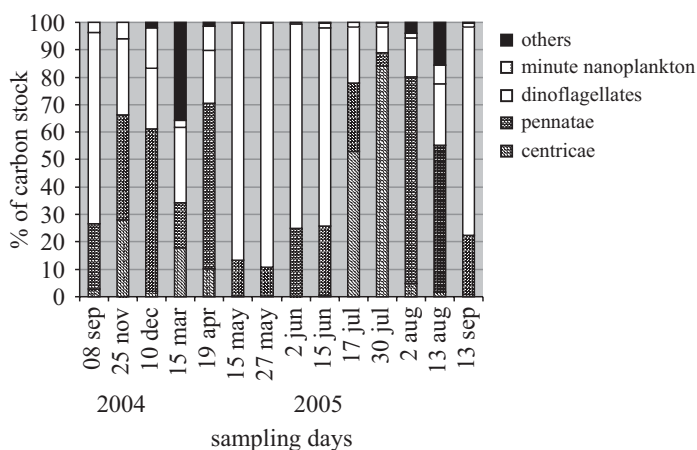


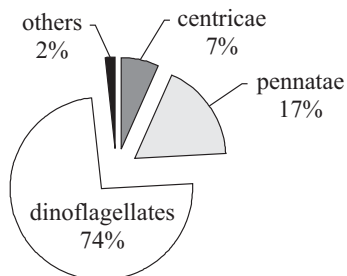
Fig. 5. Seasonal changes in phytoplankton carbon stock

consequence of the high microzooplankton grazing pressure. All the other taxonomic groups reached the maximum abundances in late spring and summer, with the exception of prymnesiophytes which had their peak in late winter.

Seasonal dynamics of phytoplankton volume and carbon showed a quite different pattern. In May, an explosive growth of large-sized dinoflagellates occurred and despite their low number (up to  $5 \times 10^4$  cells  $L^{-1}$ ), they provoked a marked increase in phytoplankton volume, rising up to  $2.7 \text{ mm}^3 L^{-1}$  (Fig. 4) and consequently in carbon stock, reaching its maximum of  $347 \mu\text{g C } L^{-1}$  (Fig. 5). In other months the carbon content never exceeded  $100 \mu\text{g C } L^{-1}$ . Thus, in terms of biovolume and carbon stock, the dinoflagellates were the most prominent group, contributing up to 90% of total carbon stock in May, between 20% and 80% in other months (Fig. 6), and with an average annual contribution of 73% (Fig. 7).



**Fig. 6.** Annual phytoplankton composition given as % of carbon stock



**Fig. 7.** Average annual contribution of different taxonomic groups to the carbon stock

## Discussion

In winter season the global solar irradiance of the area is  $15 \text{ KJ cm}^{-2}$ , while in summer it reaches a fivefold value, of  $80 \text{ KJ cm}^{-2}$  (FANUKO 1986). In the phytoplankton assemblages of the adjacent open sea an inverse fivefold increase in cell chlorophyll content was ob-

served in winter months. While in July the average monthly concentration of chlorophyll *a* per cell was 1.1 pg per cell<sup>-1</sup>, in December it rose to 5.5 pg per cell<sup>-1</sup> (FANUKO 1986). More numerous and larger chloroplasts in the winter pennate diatoms of the lagoon of Stella Maris could be the adaptation of this group to the reduced light conditions in winter. The same phenomenon was never observed in other taxonomic groups.

The number of phytoplankton species found in the lagoon of Stella Maris appeared to be high compared with other Mediterranean lagoons (Tab. 2). A higher number of species was found only in the southern part of the Lagoon of Venice (TOLOMIO and BULLO 2001), in a pool approximately 70 times larger than the Stella Maris lagoon and within 506 samples taken daily throughout the year.

**Tab. 2.** Phytoplankton diversity in several Mediterranean lagoons. <sup>1</sup>this study; <sup>2</sup>FANUKO 1980; <sup>3</sup>SARNO et al. 1993; <sup>4</sup>ANDREOLI et al. 1989; <sup>5</sup>TOLOMIO et al. 1990; <sup>6</sup>TOLOMIO and BULLO 2001; <sup>7</sup>ANDREOLI and TOLOMIO 1988

Taxonomic group	Lagoon							
	Stela Maris <sup>1</sup>	Strunjan <sup>2</sup>	Strunjan exp. <sup>2</sup>	Fusaro <sup>3</sup>	Valle Pozzolini <sup>4</sup>	Varano <sup>5</sup>	Venice lagoon Chioggia area <sup>6</sup>	Venice lagoon Valle Dogà <sup>7</sup>
Cyanobacteria	5	0	0	2	2	0	0	0
Cryptophyceae	1	0	0	3	0	0	0	0
Chrysophyceae	4	1	0	9	0	1	2	0
Prymnesiophyceae	10	9	6	2	2	12	6	0
Bacillariophyceae (Centrales)	27	28	16	38	10	15	35	7
Bacillariophyceae (Pennales)	55	47	43	18	37	50	148	96
Euglenophyceae	2	1	1	3	1	1	3	2
Dinophyceae	43	29	20	31	9	20	42	13
Chlorophyceae	4	0	0	4	1	1	0	1
<b>Total number of species</b>	<b>151</b>	<b>115</b>	<b>86</b>	<b>110</b>	<b>62</b>	<b>100</b>	<b>236</b>	<b>119</b>

Among the 198 taxa found in the adjacent open sea of the Gulf of Trieste (FANUKO 1986), 151 (76%) were also registered in the Stella Maris lagoon. In two shallow bays of the Gulf of Trieste a total of 100 species of armoured dinoflagellates were registered (FRANCE and MOZETIČ 2006) while 212 phytoplankton taxa were reported off-shore in the Gulf of Venice (BERNARDI AUBRY et al. 2006). In the more southern area off Rovinj 689 phytoplankton species were found (RELEVANTE 1986) whereas 888 species were registered for the whole Adriatic sea (VILIČIĆ et al. 2002).

In an *in situ* enrichment experiment, exhibited in the nearby lagoon of Strunjan (FANUKO 1984), the phytoplankton was significantly altered in terms of reduction of species diversity, cell density and chlorophyll biomass in the experimental lagoon which received settled municipal sewage during the period of two years. Similarly, the dystrophic

status of the shallow Santa Giusta lagoon in Sardinia (SECHI et al. 2001) remained unchanged even after waste water diversion, with blooms of the toxic *Cochlodinium polykrioides* and *Chattonella marina*, as well as the nitrophile macrobenthic alga *Ulva rigida*, whose massive proliferation in other eutrophic Mediterranean lagoons is attributed to industrial, agriculture and domestic wastes introduced in shallow lagoon waters (ACRI et al. 1995, SOCAL et al. 1999, SFRISO et al. 2003, FACCA et al. 2003). None of these algae has ever been observed in the lagoon of Stella Maris. The coccolithophorids, predominantly oceanic in distribution (HEIMDAL 1993), are completely absent in some Mediterranean lagoons (SARNO et al. 1993), but they are common in the Stella Maris lagoon. During the investigation period, 9 different species of coccolithophorids were found, among which *Acanthoica aculeata* predominated.

Tychoipelagic pennate diatoms, found in the Stella Maris lagoon, are also a representative and perennial group in the Mediterranean (ANDREOLI and TOLOMIO 1988, ANDREOLI et al. 1989, SARNO et al. 1993, SOCAL et al. 2006) and some other lagoons worldwide (CONDE et al. 1999, MACEDO et al. 2001) due to their capacity to support large and highly frequent changes in the physical conditions of the environment (BONILLA et al. 2005). Nevertheless, as shown in our study as well, other groups are responsible for the phytoplankton peaks: the small-sized pico- and nanoplankton cells (VAQUER et al. 1996) as primary producers in the microbial loop, centric diatoms, especially chain-forming *Chaetoceros spp.* and *Skeletonema sp.* (SOCAL et al. 1999, BEC et al. 2005, SOCAL et al. 2006) and finally dinoflagellates (CARRADA et al. 1991) which, due to their possible toxicity or other palatability issues, may be subject to relatively low grazing pressure (BADYLAK and PHILIPS 2004). In the northern Adriatic, *Skeletonema* has been recently identified as *S. marinoi* (SARNO et al. 2005).

The phytoplankton abundance of the Stella Maris lagoon was comparable to the oligotrophic Mar Chiquita lagoon in Argentina (DE MARCO et al. 2005). Compared to the western Adriatic lagoons (SOCAL et al. 1999, 2006) and the eutrophic Thau lagoon in France (VAQUER et al. 1996, BEC et al. 2005), values in the Stella Maris lagoon were lower by two or three orders of magnitude. Even when the unialgal blooms occurred (for example *Skeletonema sp.*), their abundances in the Stella Maris lagoon never resulted in brown tides, as was the case in the industrial area of the lagoon of Venice (SOCAL et al. 1999). The seasonal pattern of cell abundance is similar to that of other lagoons of the temperate zone, showing low winter values and summer peaks (FACCA and DE CASABIANCA 2003, FACCA et al. 2004).

The specific volume of diatom cells in the Stella Maris lagoon was higher than those found in the artificially fertilized fish ponds of the Po estuary (ANDREOLI et al. 1989), whereas the volumes of dinoflagellate species were in the same range (Tab. 3). Neglecting the possible inaccurate microscopy measurements (MONTAGNES et al. 1996) and great variations in cell size (VILIČIĆ 1985), cell volume may give better phytoplankton quantification than abundance. Great differences in diatom cell size could be explained by different diatom division rates in different environments. Probably the diatoms in the nutrient-rich pond multiplied more rapidly, with more frequent reduction in cell size.

As far as the total phytoplankton volumes and the estimated carbon content are concerned, both parameters were still lower in the Stella Maris lagoon than in Mediterranean (SARNO et al. 1993, ANDREOLI et al. 1989) and Atlantic (BADYLAK and PHILIPS 2004, BONILLA et al. 2005) lagoons.

**Tab. 3.** Average cell volume (in  $\mu\text{m}^3$ ) of some phytoplankton species in two Adriatic lagoons.<sup>1</sup>ANDREOLI et al. 1989; <sup>2</sup>this study

	Valle Pozzadini <sup>1</sup>	Stella Maris <sup>2</sup>
<b>Diatoms</b>		
<i>Chaetoceros compressus</i>	261	2650
<i>Skeletonema sp.</i>	142	2365
<i>Achnantes brevipes</i>	9075	117810
<i>Nitzschia longissima</i>	740	3351
<i>Synedra affinis</i>	1511	4500
<i>Tropidoneis lepidoptera</i>	15799	60000
<b>Dinoflagellates</b>		
<i>Prorocentrum micans</i>	16053	13090
<i>Prorocentrum minimum</i>	1379	2545
<i>Protoperidinium globulum</i>	4149	2617

Presuming that nutrients are not limiting in such a shallow environment and considering the high tidal dynamics, additionally enhanced by winds, low phytoplankton abundances might be the result of low residence time of the water inside the lagoon and its rapid export in the adjacent sea.

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